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Optoelectronic Technology Consortium

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[PRECOMPETITIVE CONSORTIUM FOR OPTOELECTRONIC INTERCONNECT TECHNOLOGY]

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Prepared by:

Dr. Mary Hibbs-Brenner (PI)
Honeywell Systems and Research Center
(612) 956-4066
fax: (612) 956-4517
MHIBBSBREN @ P01.MN09.HONEYWELL.COM

OPTOELECTRONIC TECHNOLOGY CONSORTIUM

Quarterly Technical Report No. 5
July 1 to September 30, 1993
Honeywell, Inc.

1.0 Introduction.

The Optoelectronic Technology Consortium has been established to position U.S. industry as the world leader in optical interconnect technology by developing, fabricating, integrating and demonstrating the producibility of optoelectronic components for high-density/high-data-rate processors and accelerating the insertion of this technology into military and commercial applications. This objective will be accomplished by a program focused in three areas.

Demonstrated performance: OETC will demonstrate an aggregate data transfer rate of 16 Gb/s between single transmitter and receiver packages, as well as the expandability of this technology by combining four links in parallel to achieve a 64 Gb/s link.

Accelerated development: By collaborating during the precompetitive technology development stage, OETC will advance the development of optical components and produce links for a multiboard processor testbed demonstration.

Producibility: OETC's technology will achieve this performance by using components that are affordable, and reliable, with a line BER$<10^{-15}$ and MTTF$>10^{6}$ hours.

Under the OETC program Honeywell will develop packaged AlGaAs arrays of waveguide modulators and polymer based, high density, parallel optical backplane technology compatible with low-cost manufacturability.

The packaged AlGaAs modulator arrays will consist of a single fiber input, a 1x4 fanout circuit, four waveguide modulators, and four fiber outputs, all mounted on a ceramic header. The primary benefits to this approach are enhanced system reliability, particularly at high temperatures, and a device design that is highly producible due to the inherent process tolerance. Combined with the demonstrated high density of these devices when fabricated in arrays, this allows the development of compact and reliable transmitter components.

The objective of the polyimide backplane development effort is to demonstrate a practical high density (>20 lines or channels per mm) parallel optical backplane facilitating (bandwidth x length/power) interconnect figures of merit between one and two orders of magnitude greater than would be attainable with state-of-the-art electrical interconnects. The effort will address both development of an ultimately manufacturable and

environmentally tolerant optical backplane, and the optical interface concepts required for practical board-to-backplane optical connection. The key functionalities, and compatibility with standard multiboard assembly practices will be demonstrated in a laboratory evaluation system.

Technical progress achieved during the current reporting period, and plans for the next reporting period, are summarized in the following sections.

2.0 Progress Summary.

2.1 AlGaAs Modulator Array Development. Task leader: Dr. Mary Hibbs-Brenner

During the previous reporting period, a substantial amount of data was collected on passive and active devices, allowing us to narrow the design windows for the modulator electrode lengths and for the structures which split the input beam into eight channels for the four interferometric modulators. This allowed us to design a new mask which included the appropriate bond pads which will allow modulator arrays to be packaged together with the driver chips being designed by Martin Marietta. The new mask set is illustrated in Figure 1. The upper and lower thirds of the mask contain test structures allowing us to monitor the fabrication process. The center area of the mask contains the baseline design and small variations which bracket the baseline design. Variations include 3, 4, and 5mm long electrode lengths, and MMI splitters and combiners whose lengths vary by +30μm, 0, and -30μm from the calculated optimum. This mask set can be used to fabricate the modulators to be delivered under the program.

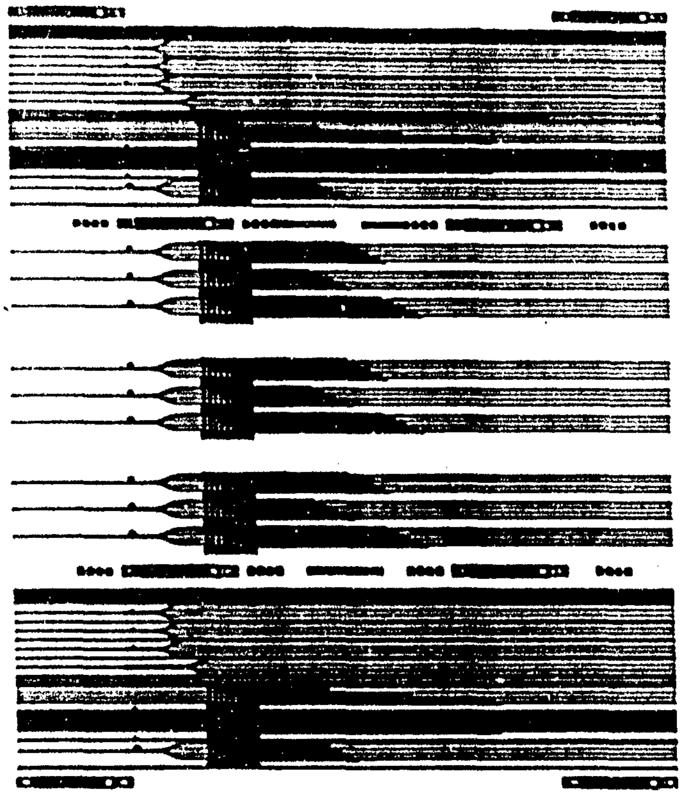

Figure 1. Mask layout for devices to be packaged as deliverables.

To date, a single process run has been carried out using the mask set described above. All but one of the runs resulted in devices with high insertion loss, due to loss at the splitters. Table 1 indicates the relationship between the splitting loss of the 1 x 4 x 8 splitters used in the modulator arrays, and the width of the waveguides etched in these samples. The design width for the waveguides was 2 μm. It can be seen that for waveguides wider than the design, the splitting loss was significantly higher (8-9 dB) than for waveguides with the correct sizing. Waveguides of width 2μm are expected to be strictly single mode, while wider waveguides, such as those of samples 78 and 150 are expected to support two modes. The multi-mode interference splitters used in this design rely on the assumption that a single mode guide abruptly changes to a guide supporting several modes. The interference between these modes results in the energy being localized into a number of maxima at particular lengths along the multi-mode region. Placing output guides at these maxima allows us to couple into several output guides with low loss. However, the presence of a second mode in the input waveguide, will disturb the multi-mode interference pattern in the splitter, thus resulting in a high splitting loss. It is this effect which we believe we are observing in the high loss samples.

Table 1. Relationship between waveguide width and excess splitter loss

Sample ID	Waveguide Width	Excess Splitter Loss 1 x 4 x 8 -dL	Baseline Design	+dL
78 D	2.5μm	-12.2 dB	-8 dB	-4.8 dB
150 C	2.4 μm	-12.1 dB	-9.2 dB	-7.5 dB
213 D	2.1 μm	*	-1.4 dB	-2.78 dB

* not working

Active devices were evaluated in the sample with low splitting loss, i.e. Sample 213. The results from an array with the calculated ideal splitter design and a 3mm long electrode are illustrated in Figure 2 and Table 2. Figure 2 plots data on the required drive and bias voltages, the peak throughput power, and the contrast ratio. The drive voltage can be seen to be quite consistent from device to device. In these tests each arm of the modulator is biased separately, requiring approximately an 8 volt single-sided voltage swing. However, the driver circuit designed by Martin Marietta will provide a complementary positive and negative voltage swings to each arm of the modulator. Four volt drive voltages will then be required, which is consistent with the specifications for the modulator driver. Modulator arrays with 4 and 5mm long electrodes will require proportionately lower voltages. Since the drivers were designed to operate over a range of 2.5 to 4 volts, almost all of the design variations should be compatible with the driver circuits. Bias voltages were also found to be relatively consistent from device to device, although the package being designed allows the bias voltage for each arm of each modulator to be tuned separately.

Table 2. Summary of performance parameters of a 4 modulator array with 3mm electrodes, baseline splitter design on sample 213D. (Note: 2 arms/modulator)

Arm #	Drive Voltage V-π (v, single-sided)	Bias Voltage (V)	Max Power Out (μW)	Contrast Ratio (dB)
1	8.0	9.1	15.7	6.3
2	7.82	12.1	17.9	9.2
3	7.83	10.8	18.0	7.4
4	7.80	10.3	20.7	13.3
5	7.80	10.0	21.6	10.3
6	8.05	11.0	20.1	17.9
7	8.01	10.6	11.5	17.2
8	8.01	10.5	10.8	33.5

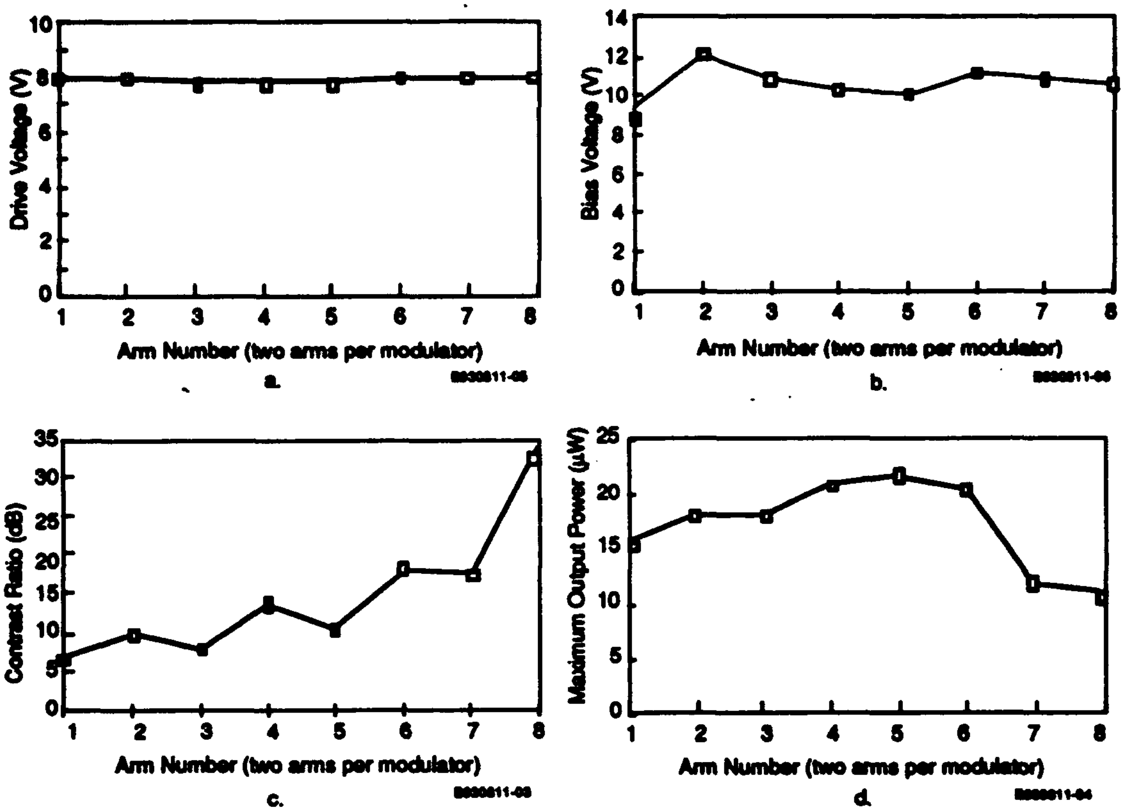

Figure 2. Performance of four element modulator array on Sample 213. Performance is plotted as a function of modulator arm number where each Mach-Zehnder modulator has 2 arms. a) Drive voltage, b) Bias voltage, c) contrast ratio, and d) Relative power output.

The peak throughput powers of the modulators varies from 10.8 to 21.6 µW, a variation of about 3dB across the array. Since these devices are not packaged, the absolute value of the throughput power is not relevant, since it depends upon the power of the input laser, and the prism coupling efficiency into the end face. However, when compared to the throughput of a straight-through waveguide (average value of 267 µW), it can be seen that the loss over and above the straight waveguide propagation loss ranges from -13.8 to -10.9 dB. This value includes an intrinsic splitting loss of 6dB. Therefore the loss due to the splitters, combiners and excess absorption under the metal electrodes ranges from -7.8 to -4.9 dB. From separate cutback experiments, propagation loss is estimated to be -5dB. Total on-chip loss (including intrinsic splitting loss) is therefore estimated at -18.8 to -15.9 dB. The contrast ratio is also plotted in Figure 2. Contrast ratio varied from 6.3 to 33.5 dB. The results of IBM link simulations have resulted in the specification that the contrast ratio exceed 6dB.

Since the modulators are being developed with the intent of providing an emitter over the full mil spec temperature range, tests were also carried out to evaluate the performance of the device as a function of temperature. A plot of the optical power transmitted through a Mach Zehnder interferometric modulator as a function of a single-ended voltage applied to one of the arms is shown in Figure 3. Four curves are shown, corresponding to 23, 50, 78 and 100 C. While the device is clearly operational up to 100 C, the contrast ratio is

somewhat degraded over the temperature range. Contrast ratio as a function of temperature (not including the effects of the change in phase) is plotted in Figure 4. The ratio degrades from 11.5 dB at room temperature to 6.5 dB at 100 C. While the goal for the contrast ratio is to be in excess of 10 dB, simulations by IBM of the link performance have indicated that contrast ratios of 6 dB are sufficient. Therefore this modulator would meet the requirements for link performance over the temperature range tested. Additional measurements have indicated that the change in contrast ratio with increasing temperature is a result of a polarization rotation which takes place within the devices and which changes as a function of temperature. We suspect that this is due to residual stress in the device. We are currently testing this assumption, as well as our assumptions as to the source of this stress. Results from these experiments will be included in the next quarterly report.

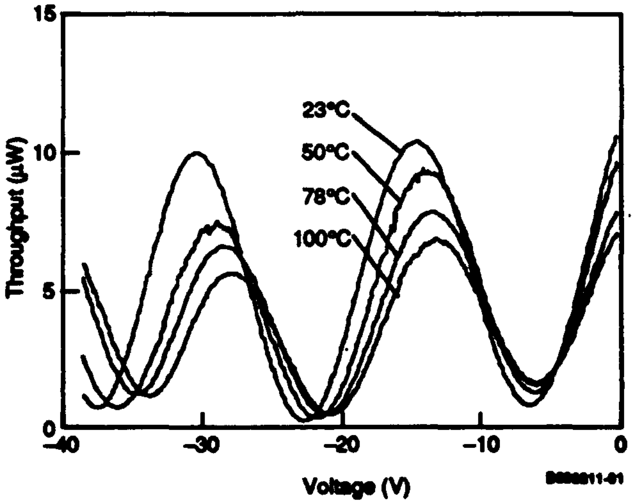

Figure 3. Light versus voltage for Sample 213 over a 23-100° C temperature range.

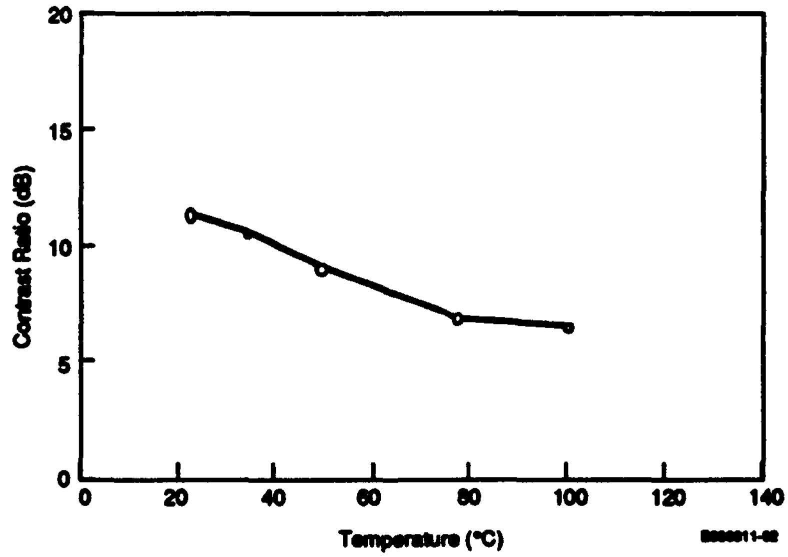

Figure 4. Contrast ratio versus temperature for Sample 213.

2.2 AlGaAs Modulator Array Packaging. Task leader: Mr. John Lehman

During the current reporting period the alumina components which comprise the modulator package have been fabricated and are currently being assembled. In addition, an optical subassembly consisting of the pigtailed modulator array was assembled as a demonstration. Figure 5 shows a photograph of the subassembly. The AlGaAs chip, seen in the photograph, consists of 8 arrays of 4 modulators each, for a total of 32 Mach-Zehnder modulators. Each array has one single-mode input waveguide which splits into 8 channels for the modulators. The two arms of each modulator recombine after the metal electrodes. Optical fiber was coupled to the input and output channels of a single four modulator array. A single mode, polarization-preserving fiber (coming in from the left of the photograph) is attached to the alumina platform after active alignment. Four multimode fibers (going off to the right), mounted in a silicon v-groove are aligned to couple the light out of the array. Since this was one of our first experiments at producing a full optical assembly, a device was used in which the on-chip losses were not well-characterized. Therefore, quantitative numbers for input and output coupling losses were not obtained.

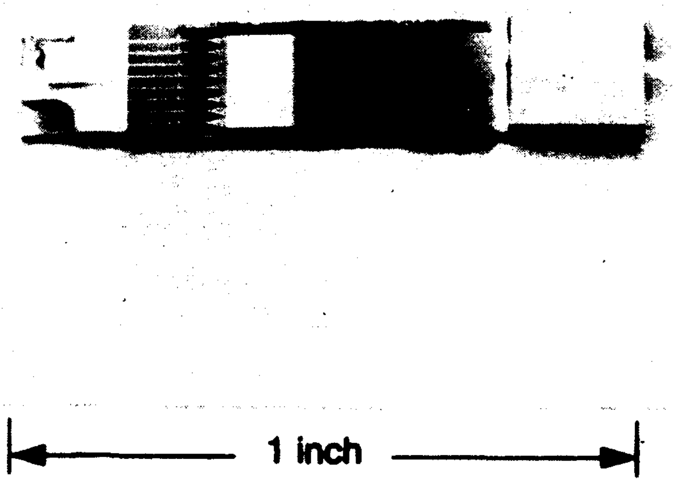

Figure 5. Photo of a modulator array chip containing 8 four element modulator arrays single mode polarization maintaining fiber is aligned to the input of one array, with four multi-mode fibers aligned to the output.

2.3. Polymer Backplane Development. Task leader: Dr. Julian Bristow

During this quarter we have completed the connector components for integration into the board and polymer backplane. The connector fixtures have been made from a machinable ceramic using a design which will ultimately allow the ceramic fixtures to be mass produced using standard molding techniques. Lenses have been polished and integrated with the connector fixtures. The half gradient index lenses have been fabricated using sawing and polishing. An initial evaluation of the tolerances indicates that the lens preparation technique can also be extended to mass production.

3.0. Next quarter plans.

3.1. AlGaAs Modulator Array Development.

The next quarter's effort will be concentrated on understanding the behavior of the modulator devices as a function of temperature. This will include looking at the effects of factors such as oxide passivation, metal electrode deposition, reactive ion etching and material growth on the stress generated in the devices. In addition, techniques for monitoring the fabrication process in order to produce waveguides with the designed width will be developed. This information, along with any information regarding the reduction of induced stress will be incorporated into the process, and another process run will be carried out to produce additional devices suitable for packaging as deliverables. This process run will be carried out using the current mask set.

3.2. AlGaAs Modulator Array Packaging.

During the next quarter we will be assembling complete packages including the four channel modulator arrays, the input and output fibers, the modulator drivers being provided by Martin Marietta, and the bias tee network providing the bias voltages to the modulators. We will begin evaluating the input and output coupling losses. High speed electrical testing will require a test board which will either be provided by Martin Marietta or will be procured at the same time Martin Marietta places their order. Therefore, full testing at speed will probably not take place until the seventh quarter.

3.3. Polymer Backplane Development.

In preparation for the final demo, a mask for patterning the polymer waveguides to be fabricated on the boards will be designed and sent out for fabrication. Upon receipt of the mask, polymer waveguides will be deposited and etched on the boards to be used in the final demo. The assembly of the board with the connector fixtures will be carried out in the seventh quarter of the program.

4.0. Summary.

Effort during the current quarter has included the fabrication of a four modulator array with the footprint, pinout, drive voltage, bias voltage, and contrast ratio required for the optical link, and the demonstration of the operation of the modulators at temperatures up to 100 C.. Two residual problems have been identified: 1) the sensitivity of splitter loss to the width of the input waveguide, and 2) a reduction in contrast ratio over temperature due to polarization rotation which is a function of temperature. A process monitor is being developed to ensure that waveguides of the designed width are produced in future runs. The effect and source of stress resulting in polarization rotation is also being examined. While stress and its effect on polarization rotation is a continuing problem, it should be noted that its effect on contrast ratio has been drastically reduced from levels observed earlier in the program. Modulator arrays suitable for packaging as deliverables are expected to be fabricated in the next quarter.

The pieceparts for the modulator array package are being fabricated and are expected to be delivered early in the next quarter. An optical subassembly has been assembled which included a modulator array, single mode-input fiber, and four multi-mode output fibers. During the next quarter, quantitative evaluation of the losses in this assembly will be carried out. In addition, a mechanical model of a full package including the optical subassembly, modulator driver, and bias tee network will be fabricated. Evaluation of the performance of the package will be initiated.

Prototype connector fixtures for the polymer backplane demonstration have been fabricated in this quarter. Next quarter, the waveguide pattern for the demonstration will be designed and fabricated.